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DIPARTIMENTO DI TECNICA E GESTIONE DEI SISTEMI INDUSTRIALI

SUSTAINABLE MOBILITY

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Abstract

This thesis presents a comprehensive study on developing a machine learning model to predict mobility patterns in various weather conditions and group structures. The primary focus of this project is to assess the effectiveness of machine learning models in forecasting mobility behavior, considering different weather scenarios, social contexts, and route characteristics. Additionally, the research aims to identify the key factors influencing mobility behavior and explore the potential application of machine learning models in personalized mobility prediction and sustainable transportation planning.

To achieve these objectives, a range of machine learning models will be evaluated for their accuracy and precision in forecasting mobility patterns. The research will investigate how different models perform in predicting mobility behavior under varying weather conditions and social contexts. Moreover, an in-depth analysis will be conducted to identify the factors that significantly impact the accuracy of these models.

By examining the accuracy and precision of various machine learning models, this research will provide valuable insights into their effectiveness in mobility forecasting. Furthermore, it will uncover the factors that play a crucial role in influencing the accuracy of these models. The findings of this study will contribute to the advancement of machine learning applications in transportation planning and assist in developing personalized mobility prediction systems for sustainable transportation.

Keywords: machine learning, mobility patterns, weather conditions, group structures, accuracy, precision, personalized mobility prediction, sustainable transportation planning

Astratto

Questa tesi presenta uno studio approfondito per lo sviluppo di un modello di apprendimento automatico per prevedere i modelli di mobilità in diverse condizioni meteorologiche e strutture di gruppo. Il focus principale di questo progetto è

valutare l'efficacia dei modelli di apprendimento automatico nella previsione del comportamento di mobilità, considerando diversi scenari meteorologici, contesti sociali e caratteristiche del percorso. Inoltre, la ricerca mira a identificare i fattori che influenzano il comportamento di mobilità ed esplorare la possibilità di utilizzare i modelli di apprendimento automatico per la previsione della mobilità personalizzata e la pianificazione del trasporto sostenibile.

Per raggiungere questi obiettivi, verranno valutati diversi modelli di apprendimento automatico per la loro accuratezza e precisione nella previsione dei modelli di mobilità. La ricerca indagherà su come diversi modelli si comportano nella previsione del comportamento di mobilità in diverse condizioni meteorologiche e contesti sociali. Inoltre, verrà condotta un'analisi approfondita per identificare i fattori che influenzano in modo significativo l'accuratezza di questi modelli.

Attraverso l'esame dell'accuratezza e della precisione dei vari modelli di apprendimento automatico, questa ricerca fornirà preziose intuizioni sulla loro efficacia nella previsione della mobilità. Inoltre, svelerà i fattori che giocano un ruolo cruciale nell'influenzare l'accuratezza di questi modelli. I risultati di questo studio contribuiranno all'avanzamento delle applicazioni di apprendimento automatico nella pianificazione dei trasporti e aiuteranno nello sviluppo di sistemi di previsione della mobilità personalizzata per il trasporto sostenibile.

Parole chiave: apprendimento automatico, modelli di mobilità, condizioni meteorologiche, strutture di gruppo, accuratezza, precisione, previsione della mobilità personalizzata, pianificazione del trasporto sostenibile.

Acknowledgement

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1 Introduction

With the rapid expansion of cities and the escalating worries regarding the sustainable use of our natural resources, the quest for achieving transportation systems that are not only efficient but also eco-friendly has garnered significant attention and become an urgent global challenge. Sustainable mobility, often referred to as sustainable transportation, aims to develop and implement strategies that promote the efficient movement of people and goods while minimizing negative environmental and social impacts.

Furthermore, machine learning, a field of artificial intelligence, involves the development and application of computational models that can automatically learn and improve from data without explicit programming. By analyzing large and diverse datasets, machine learning algorithms can identify patterns, make predictions, and gain valuable insights that aid decision-making processes. In the context of sustainable mobility, machine learning can provide innovative solutions to optimize transportation systems, improve accessibility, and minimize environmental impact.

Optimizing transportation systems through machine learning involves the application of data analytics to enhance operational efficiency, reduce congestion, and improve the overall performance of transportation networks. By processing large volumes of data collected from sources such as traffic sensors, GPS devices, and social media platforms, machine learning algorithms can generate real-time traffic predictions, optimize routing, and dynamically adapt transportation services. These advancements lead to improved travel experiences, reduced travel times, and more efficient allocation of resources.

Accessibility is a key aspect of sustainable mobility, aiming to ensure that transportation services are available and equitable for all individuals, regardless of their physical abilities, income levels, or geographic location. Machine learning algorithms can help address accessibility challenges by analyzing data on travel demand, demographics, and infrastructure characteristics. This enables the identification of underserved areas, optimization of transit routes, and the design of transportation services that cater to the needs of diverse populations.

Environmental sustainability is another critical dimension of sustainable mobility. Transportation accounts for a significant portion of global greenhouse gas emissions and is a major contributor to air pollution. Machine learning can play a crucial role in minimizing the environmental impact of transportation by developing predictive models that estimate emissions, optimize energy consumption, and facilitate the integration of clean and renewable energy sources. Additionally, machine learning techniques can aid in the design of eco-routing algorithms, which suggest the most environmentally friendly travel routes based on real-time data.

In summary, the combination of machine learning and sustainable mobility presents a promising framework to address the complex challenges faced by transportation systems. By harnessing the power of machine learning algorithms, transportation stakeholders can optimize operations, improve accessibility, and mitigate environmental impact. As the demand for sustainable and efficient mobility solutions continues to grow, machine learning can provide valuable insights and tools to shape the future of transportation, leading to more sustainable, accessible, and environmentally friendly mobility systems.

1.1 Motivation and Problem Statement

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[**Jurgens:2000**, **Jurgens:1995**, **Miede:2011**, **Kohm:2011**, **Apple:keynote:2010**, **Apple:numbers:2010**, **Apple:pages:2010**]

1.2 Results

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1.2.1 Some References

[**WEB:GNU:GPL:2010**, **WEB:Miede:2011**] And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should

show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Methodology

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Strategy 1 Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

```
1 #!/usr/bin/env python
2 print "Hello World"
```

Listing 1.1: This simple helloworld.py file prints Hello World.

Strategy 2 This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

```
#!/usr/bin/env python
def bubble_sort(list):
    for num in range(len(list)-1,0,-1):
        for i in range(num):
            if list[i]>list[i+1]:
                tmp = list[i]
                list[i] = list[i+1]
                list[i+1] = tmp

alist = [34,67,2,4,65,16,17,95,20,31]
bubble_sort(list)
print(list)
```

Listing 1.2: This is a bubble sort function.

1.3 Thesis Structure

Chapter ??

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Chapter 3

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Chapter 4

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Chapter 5

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Data Analysis

2

> *Information is the oil of the 21st century, and analytics is the combustion engine.*
>
> — **Peter Sondergaard**
> (Founder of The Sondergaard Group, LLC.)

This chapter discusses data analysis methodologies. Collaborating with Mowi Space, a platform tailored for mountain biking enthusiasts and winter sports enthusiasts, this collaboration has yielded a dynamic digital platform catering to outdoor sports. The MOWI website offers real-time data and interactive 3D maps for offline exploration. It delivers current trail conditions, weather updates, lift operations, and local events, ensuring informed and safe adventures. Notably, the Live Track feature allows real-time monitoring of family or friends during mountain activities, fostering connectivity and safety. This collaboration signifies a pivotal advancement in outdoor experience planning, merging technology with nature's allure.

As a result of getting some user's data going through various tracks, it's possible to convert the GPS data into CSV files.

2.1 Converting the GPS data

This Python code snippet performs data processing on GPS data from GPX files and converts it into a more analyzable CSV format. The code utilizes several libraries for various functionalities.

2.1.1 Imports

The script begins by importing necessary Python libraries:

```
import gpxpy
import gpxpy.gpx
import numpy as np
import haversine as hs
import pandas as pd
import os
import gpxpy
import pandas as pd
from tqdm import tqdm
```

These libraries are used for working with GPX files, numerical calculations, data manipulation, and progress tracking during processing.

2.1.2 Functions

The code defines several important functions:

gpx_to_csv

This function converts GPX data to CSV format and calculates various metrics.

```
def gpx_to_csv(gpx_file_path, csv_file_path):
    with open(gpx_file_path, 'r') as gpx_file:
        gpx = gpxpy.parse(gpx_file)

    route_info = []
    for track in gpx.tracks:
        for segment in track.segments:
            for point in segment.points:
                route_info.append({
                    'time': point.time,
                    'latitude': point.latitude,
                    'longitude': point.longitude,
                    'altitude': point.elevation
                })

    route_df = pd.DataFrame(route_info)

    route_df['altitude_diff'] = route_df['altitude'].diff()
    route_df['relative_elevation'] = route_df['altitude_diff'
        ].cumsum()
```

```
    distances = [np.nan]
    speed = [np.nan]

    for i in range(1, len(route_df)):
        distances.append(haversine_distance(
            lat1=route_df.iloc[i - 1]['latitude'],
            lon1=route_df.iloc[i - 1]['longitude'],
            lat2=route_df.iloc[i]['latitude'],
            lon2=route_df.iloc[i]['longitude']
        ))

        # #* speed
        time_diff = (route_df.iloc[i].time - route_df.iloc[i
            - 1].time).seconds
        distances_i = distances[i]

        # Handling division by zero
        if time_diff == 0:
            speed_i = 10  # Assign an appropriate default
                value
        else:
            speed_i = distances_i / time_diff

        speed.append(speed_i)

    route_df['distance'] = distances
    route_df['cum_distance'] = route_df['distance'].cumsum()
        /1e3
    route_df['speed'] = speed

    number_of_lifts = lift_checker(route_df)
    if number_of_lifts > 0:
        report.append({
            'file': csv_file_path[11:],
            'n': number_of_lifts,
            'sum_of_n': route_df['lift_path'].sum()/2
        })
        print('-----------------------------------')
        print(f"The number of lifts detected on {
            csv_file_path[11:]} is {number_of_lifts}")
        print('-----------------------------------')

    route_df = route_df.fillna(0)  # replace NANs with zero
```

```
    ######
    route_df.to_csv(csv_file_path, index=False)
    return route_df
```

1. The function first parses the input GPX file using the *gpxpy* library and extracts key data like time, latitude, longitude and elevation into a Python dictionary for each point along the route.
2. It then converts this dictionary into a Pandas DataFrame to enable easier data manipulation.
3. Additional columns are created in the DataFrame to calculate elevation difference, cumulative elevation gain, distance between points, cumulative distance, and speed based on the time difference between points.
4. Potential divide-by-zero errors are handled when calculating speed.
5. A lift detection function is called to analyze the elevation profile and count the number of detected lifts along the route.
6. The number of detected lifts is tracked in a report.
7. Missing data in the DataFrame is filled with zeros.
8. Finally, the processed DataFrame is written out to a CSV file to save the updated route data.
9. The code returns the final DataFrame containing the enriched route data with statistics like speed, distance, elevation, and lift counts.

`haversine_distance`

In the previous function, the implementation leverages the functionality of two additional functions. Firstly, an auxiliary function is employed to compute the haversine distance, which quantifies the geographical distance between two distinct sets of latitude and longitude coordinates. This computation is facilitated through the utilization of the `haversine` library.

```
def haversine_distance(lat1, lon1, lat2, lon2) -> float:
    distance = hs.haversine(
        point1=(lat1, lon1),
        point2=(lat2, lon2),
        unit=hs.Unit.METERS
```

```
    )
    return np.round(distance, 2)
```

lift_checker

Furthermore, an additional vital function comes into play. This function is dedicated to the identification of lift occurrences in the dataset. In the event a lift is detected, this function augments the existing DataFrame of GPS data with two supplementary columns. The first column, designated as `lift?`, is equipped with boolean values to indicate the presence of a lift at specific points. The second column, titled `lift_path`, serves as an indicator for lift pathways, allowing for the demarcation of paths corresponding to lift usage:

```
def lift_checker(df):
    number_of_lifts = 0
    df['lift?'] = 0  # ? set the "lift?" column to zero
    df['lift_path'] = 0

    for i in range(len(df)):
        if df['altitude_diff'][i] > 100:
            number_of_lifts += 1
            df.loc[i, 'lift?'] = 1
            df.loc[i-1:i, 'lift_path'] = 1

    return number_of_lifts
```

convert_all_gpx_to_csv

This function processes all GPX files in a directory and converts them to CSV:

```
def convert_all_gpx_to_csv(gpx_dir, csv_dir):
    gpx_files = [filename for filename in os.listdir(
        gpx_dir) if filename.endswith('.gpx')]
    progress_bar = tqdm(total=len(gpx_files), desc="
       Converting GPX files")
    for filename in gpx_files:
        gpx_file_path = os.path.join(gpx_dir, filename)
        csv_file_path = os.path.join(csv_dir, filename.
           replace('.gpx', '.csv'))
        gpx_to_csv(gpx_file_path, csv_file_path)
```

```
            progress_bar.update(1)
        progress_bar.close()
```

2.1.3 Main Execution

Eventually, the *convert_all_gpx_to_csv* function is invoked by providing it with the relevant directories for input GPX files (*gpx_dir*) and output CSV files (*csv_dir*). As the function iterates through each GPX file, it performs the necessary conversions and progress is visually indicated through status updates. After the conversion process concludes, a report is generated to catalog tracks that contain a minimum of one lift. This report is structured as a DataFrame and subsequently saved as a CSV file named *report.csv* within the designated data directory. The overall result is a seamless conversion of raw GPS data into a more structured and informative format, followed by the generation of a comprehensive report for further analysis.

```
# Usage
gpx_dir = './data/gpx_train/'
csv_dir = './data/csv_train/'
convert_all_gpx_to_csv(gpx_dir, csv_dir)
print('Converting is finished.')

# Generating a report of the tracks that have at least one
    lift
report_df = pd.DataFrame(report)
report_df.to_csv('./data/report.csv', index=True)
```

2.2 Utilizing the CSV data

2.3 Conclusion

3 System

> *Innovation distinguishes between a leader and a follower.*
>
> **— Steve Jobs**
> (CEO Apple Inc.)

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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3.1 System Section 1

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Fig. 3.1.: Figure example: *(a)* example part one, *(c)* example part two; *(c)* example part three

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3.2 System Section 2

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Fig. 3.2.: Another Figure example: *(a)* example part one, *(c)* example part two; *(c)* example part three

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3.4 Conclusion

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4

Concepts: This text is here to test a very long title, to simulate the line break behavior, to show that an extremely long title also works

> *Users do not care about what is inside the box, as long as the box does what they need done.*
>
> **— Jef Raskin**
> about Human Computer Interfaces

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4.1 Concepts Section 1

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4.2 Concepts Section 2 with a very very long title that illustrates how long section titles are handled in the footer

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5.2 System Section 2

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5.3 Future Work

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Example Appendix

A

This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

A.1 Appendix Section 1

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Alpha	Beta	Gamma
0	1	2
3	4	5

Tab. A.1.: This is a caption text.

A.2 Appendix Section 2

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like

at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Alpha	Beta	Gamma
0	1	2
3	4	5

Tab. A.2.: This is a caption text.

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

Colophon

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Declaration

You can put your declaration here, to declare that you have completed your work solely and only with the help of the references you mentioned.

Padova, September 05, 2023

Nima Karimi